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Ohyama

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(54) LIQUID TREATMENT APPARATUS INCLUDING FLOW CHANNEL, FIRST AND SECOND ELECTRODES, INSULATOR SURROUNDING LATERAL SURFACE OF FIRST ELECTRODE, GAS SUPPLY DEVICE, AND POWER SUPPLY SOURCE

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H01J 37/32 (2006.01)
H05H 1/24 (2006.01)

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CPC C02F 1/4608; C02F 2305/023; C02F 2301/043; C02F 2301/046; C02F 2303/04; H01J 37/32807; H01J 37/3244; H01J 37/32541; H01J 37/32761; H01J 2237/038; A61L 12/14; B01J 19/088
See application file for complete search history.

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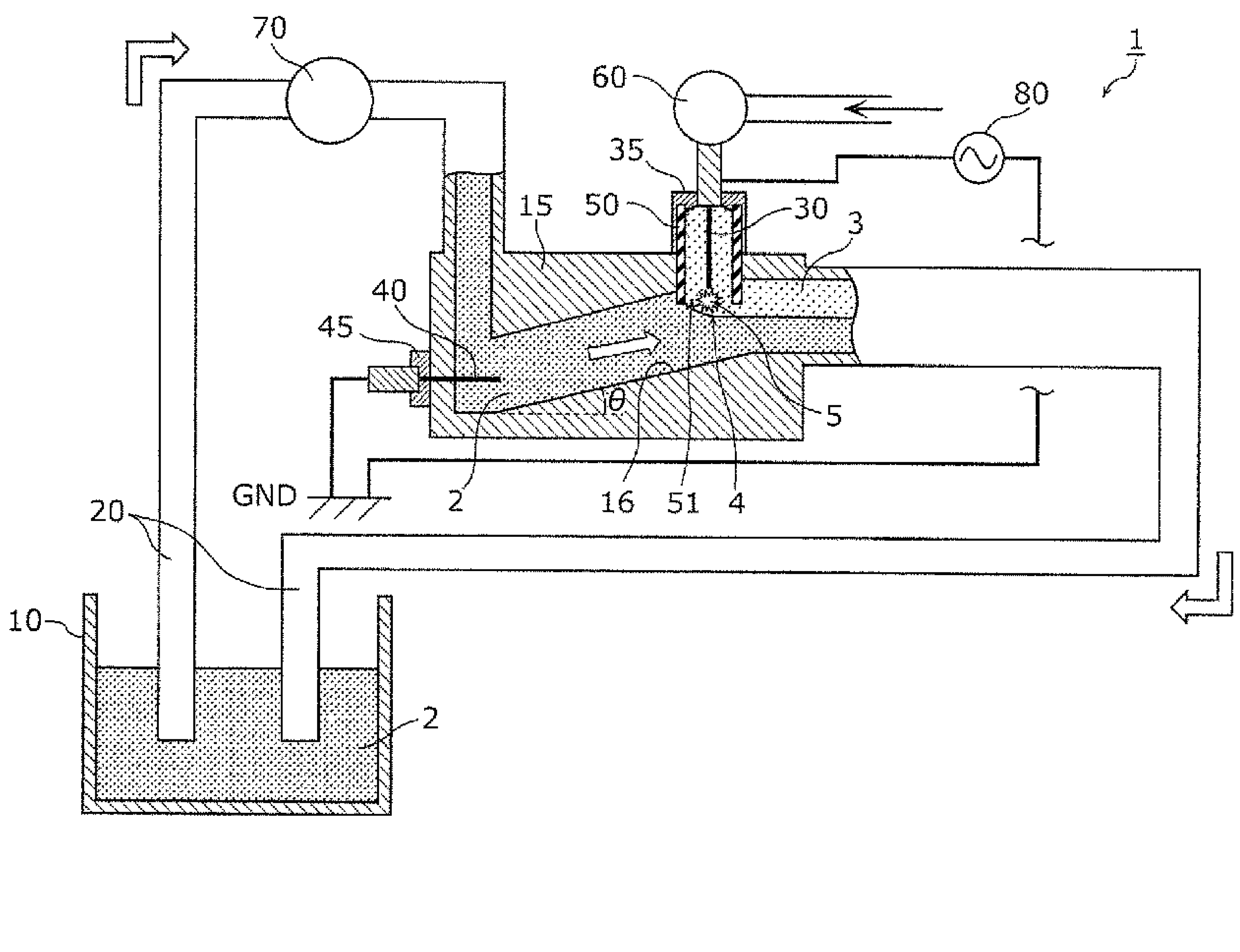
(57) **ABSTRACT**

A liquid treatment apparatus includes a flow channel, first and second electrodes at least part of each of which is disposed within the flow channel, an insulator, a gas supply device, and a power supply source that applies a voltage between the first and second electrodes and generates plasma. The insulator has a tubular shape and an opening on an end surface of the insulator, and surrounds a lateral surface of the first electrode with a space interposed between the insulator and the first electrode. The gas supply device supplies and ejects a gas into the liquid via the opening. At least part of the flow channel extends in a first direction which is inclined with respect to a horizontal direction so that the liquid flows obliquely upward with respect to the horizontal direction. The opening is positioned within the at least part of the flow channel.

6 Claims, 7 Drawing Sheets



(52) **U.S. Cl.**
CPC .. ***H01J 37/32541*** (2013.01); ***H01J 37/32761*** (2013.01); ***H05H 1/2406*** (2013.01); *C02F 2301/043* (2013.01); *C02F 2301/046* (2013.01); *C02F 2303/04* (2013.01); *C02F 2305/023* (2013.01); *H01J 2237/038* (2013.01); *H05H 2001/2412* (2013.01); *H05H 2001/2431* (2013.01); *H05H 2240/10* (2013.01)

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FIG. 1

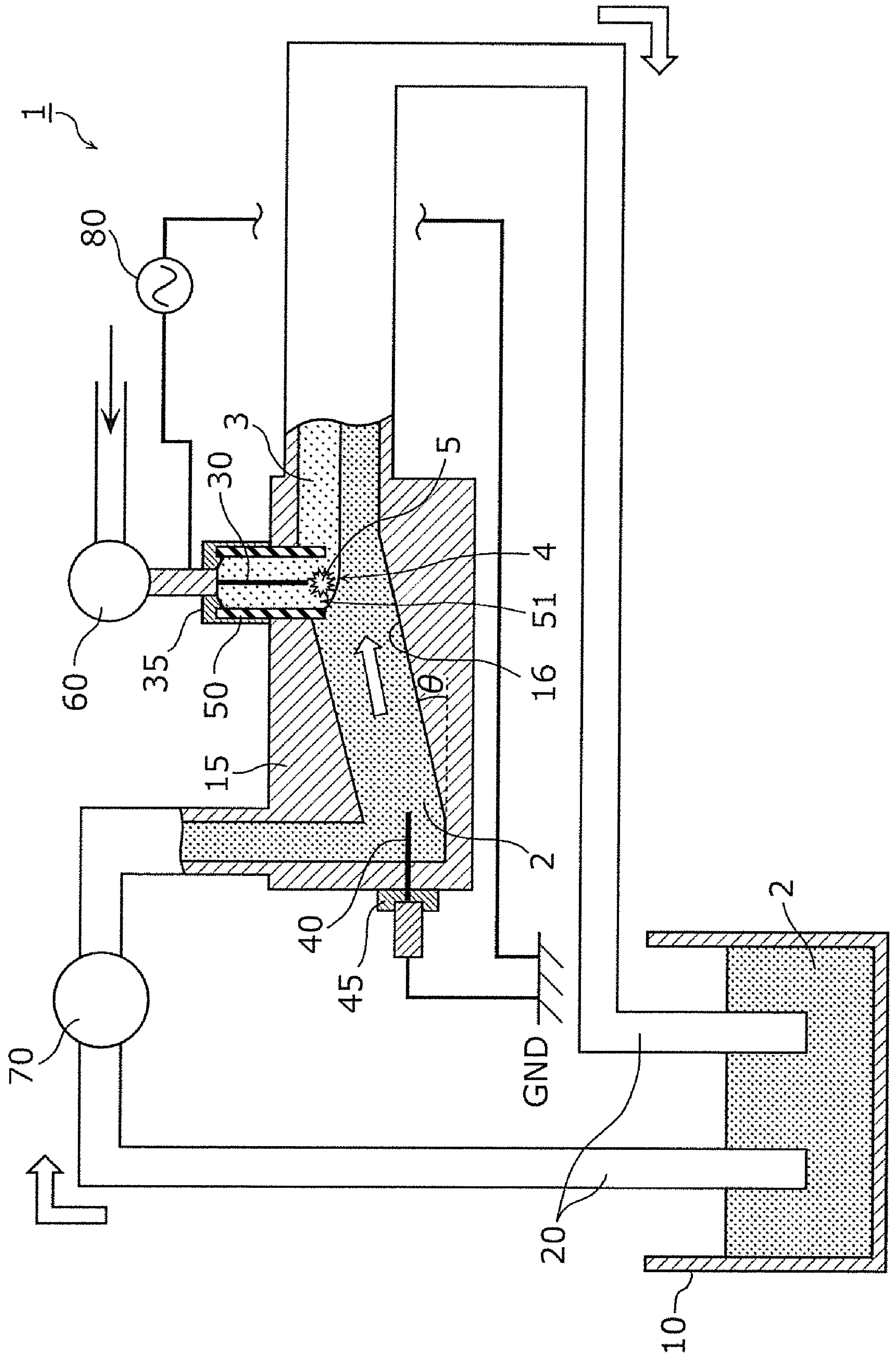


FIG. 2

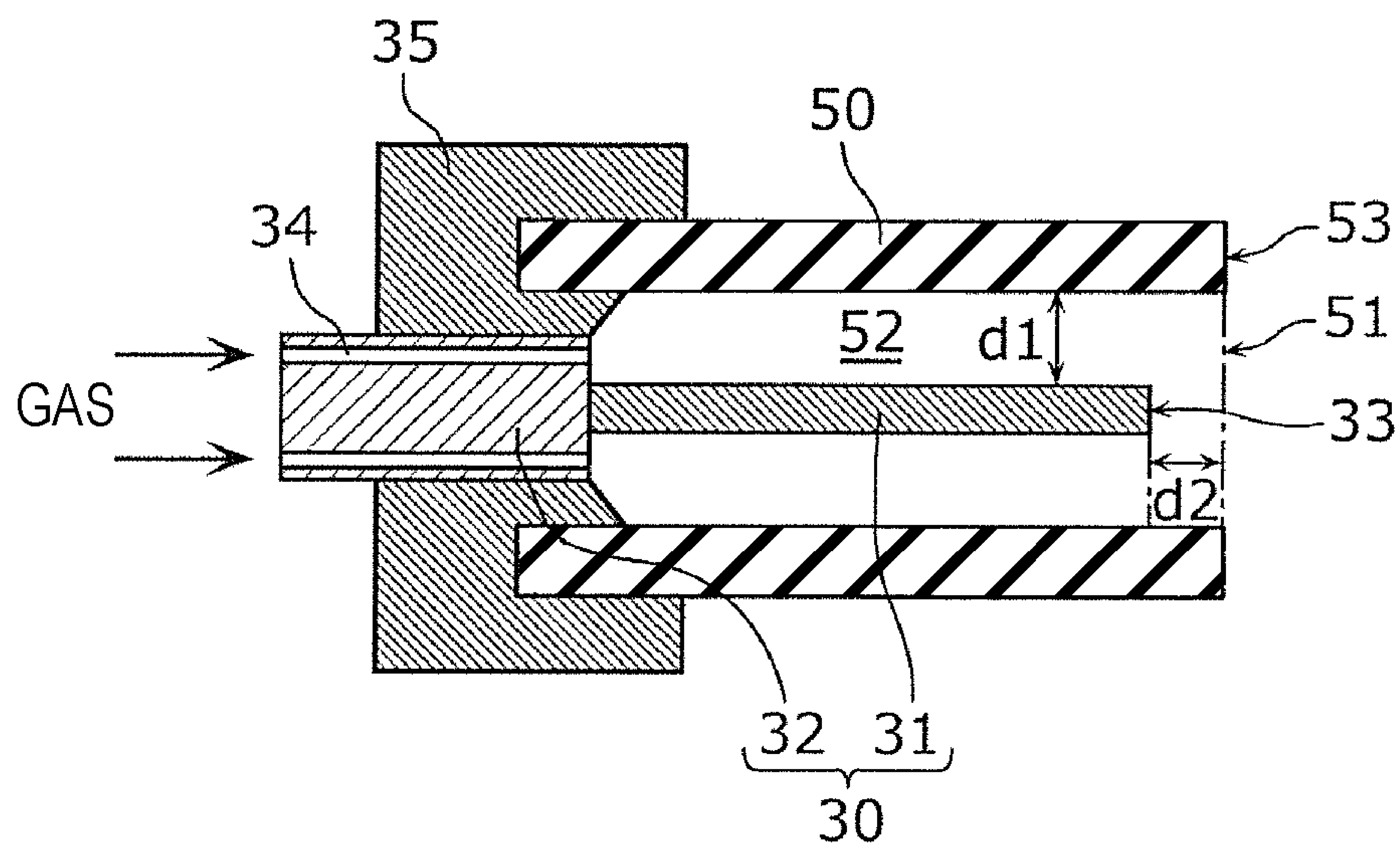


FIG. 3

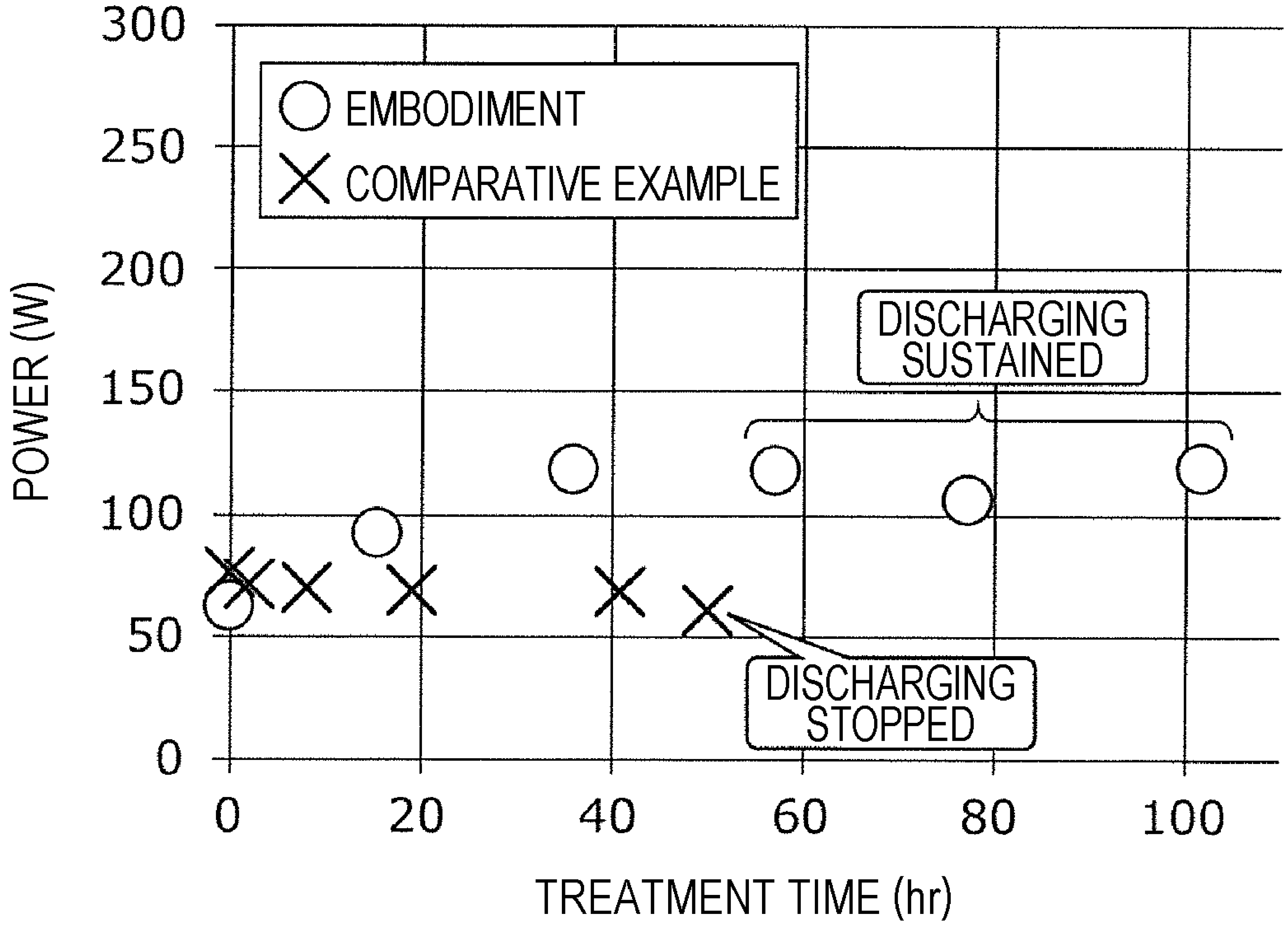

EMBODIMENT
COMPARATIVE EXAMPLE
DISCHARGING SUSTAINED
DISCHARGING STOPPED
POWER (W)
300
250
200
150
100
50
0
0
20
40
60
80
100
TREATMENT TIME (hr)

FIG. 4

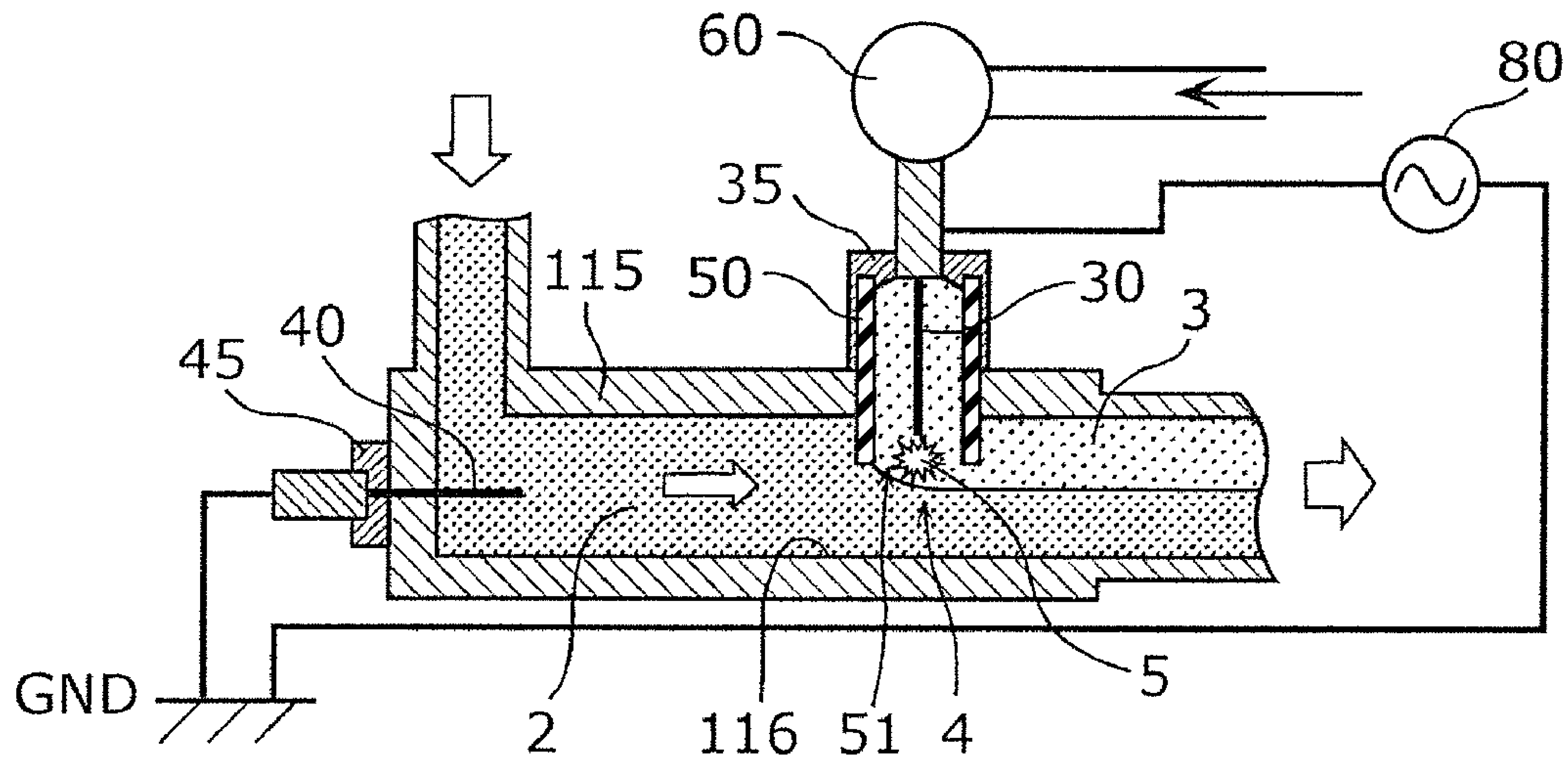


FIG. 5

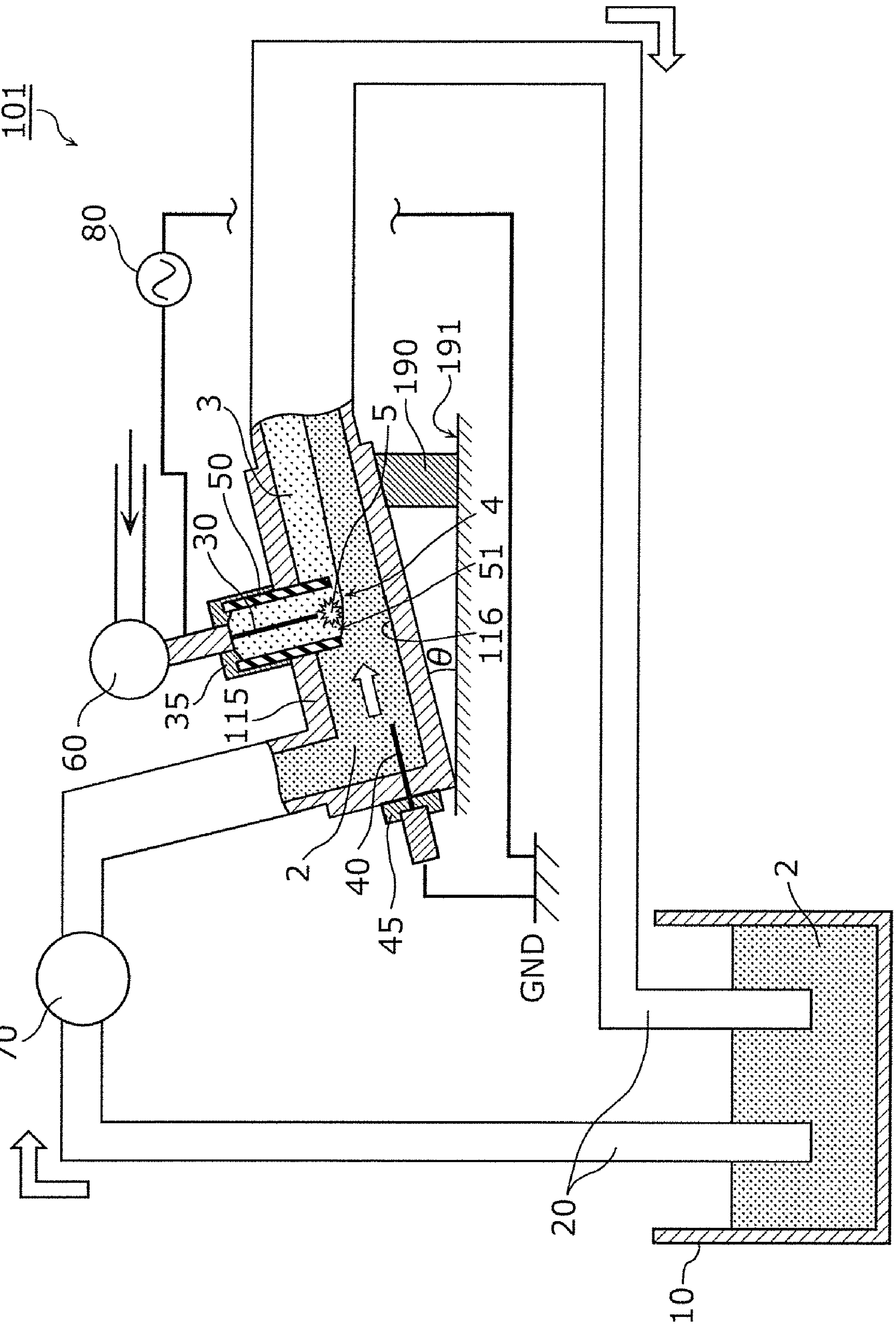


FIG. 6

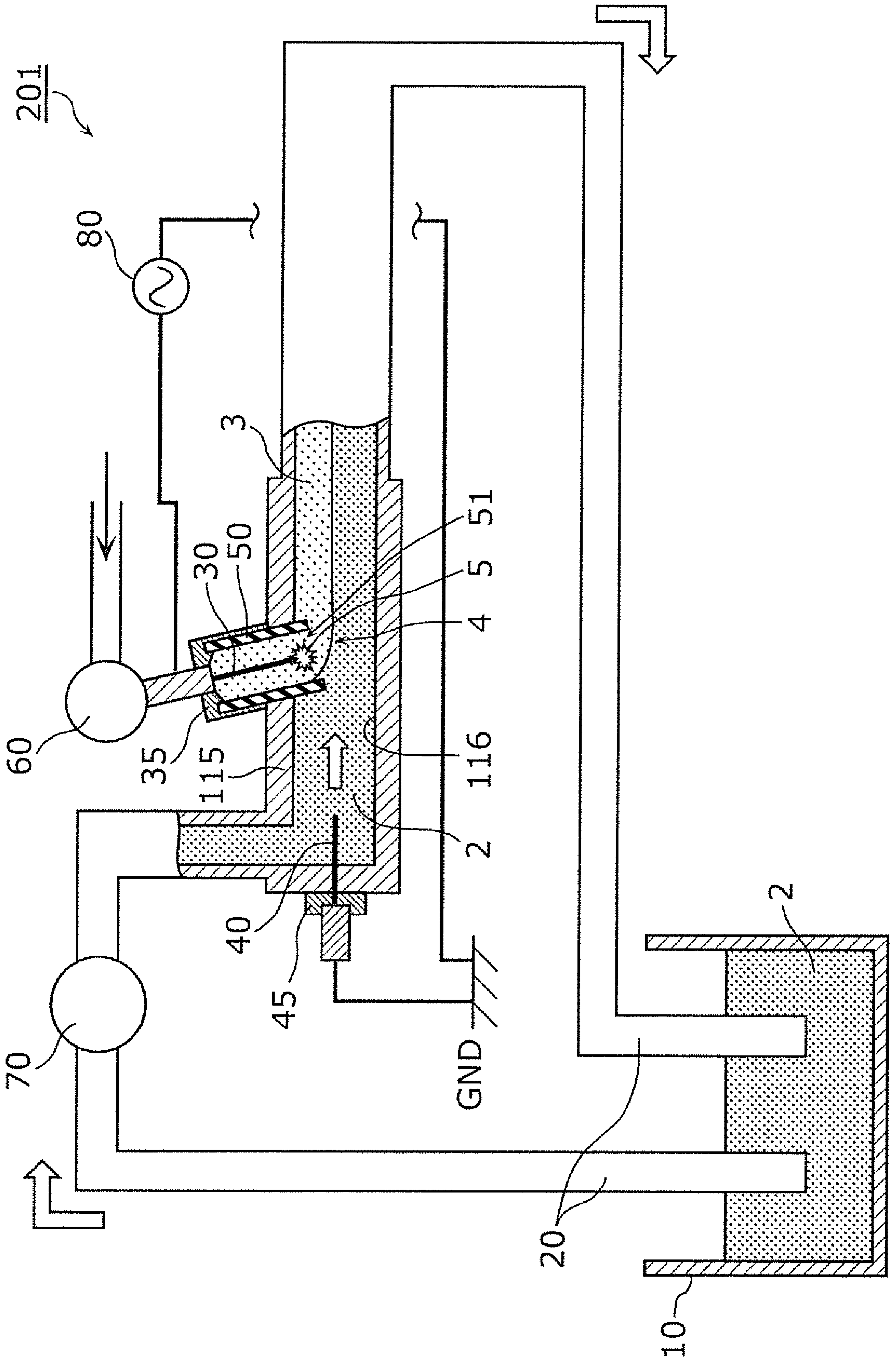


FIG. 7

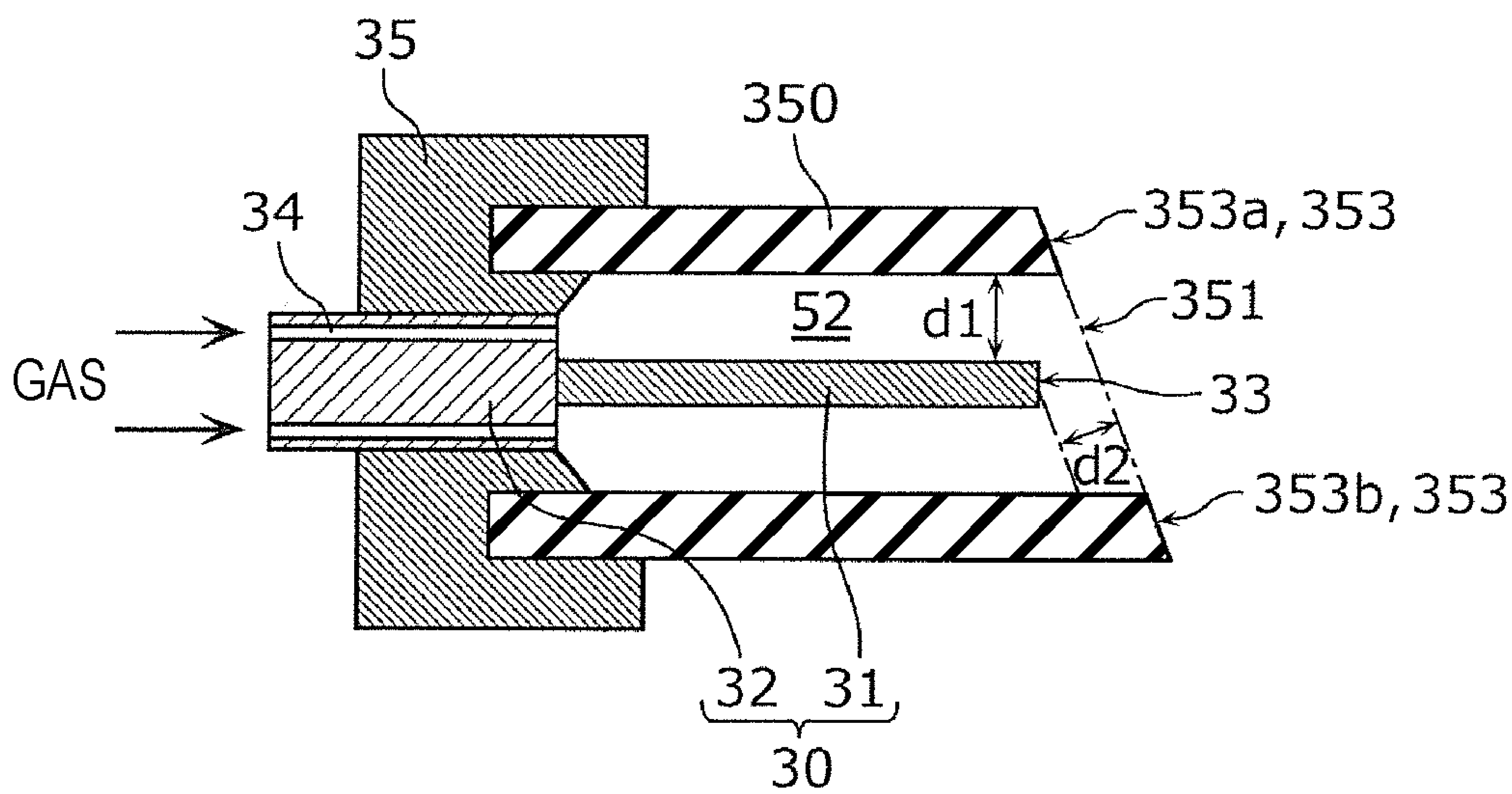
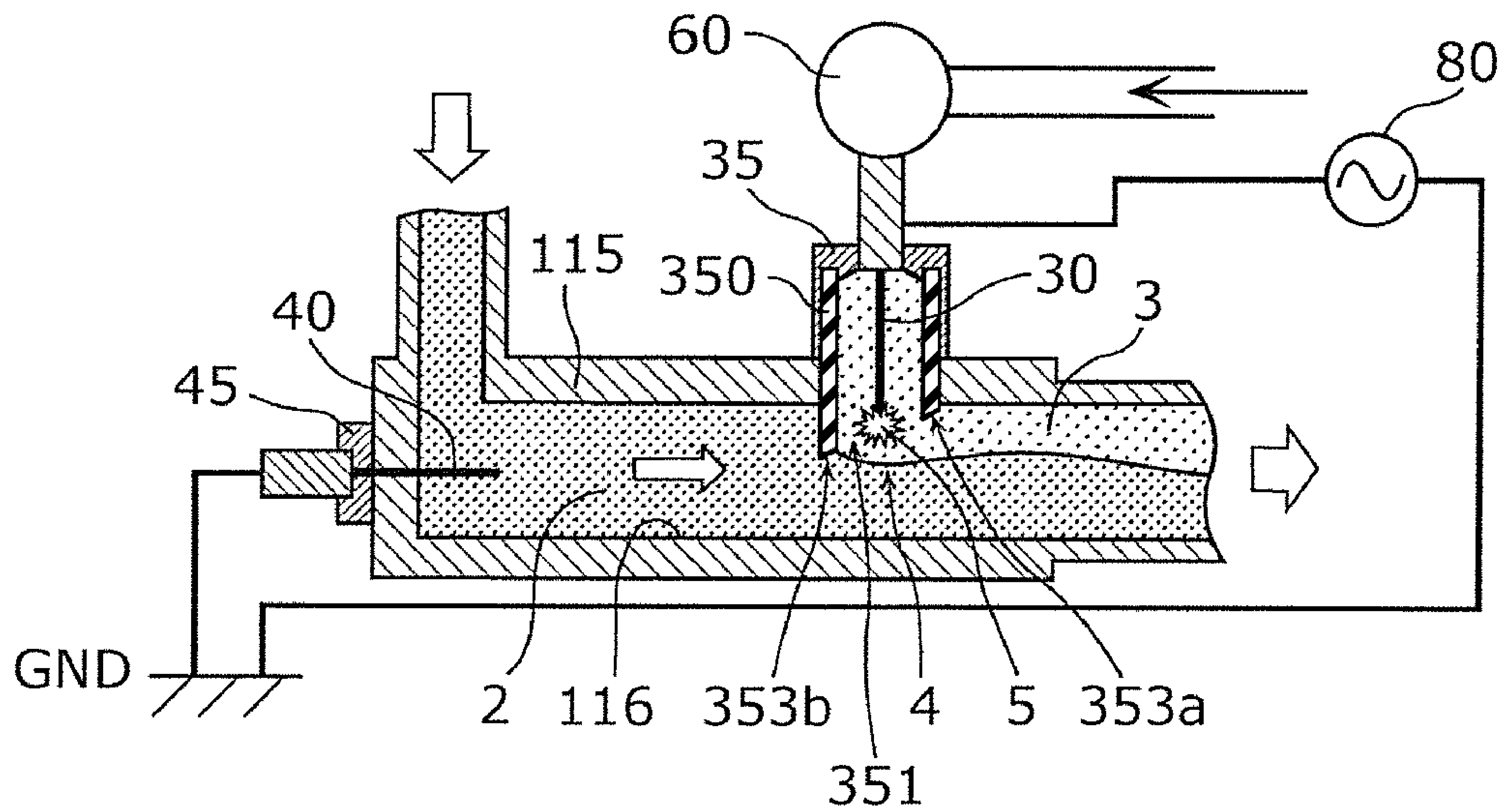

35
350
34
353a, 353
351
52
d1
GAS
33
d2
353b, 353
32
31
30

FIG. 8


60
80
35
115
350
30
3
40
45
GND
2
116
353b
4
5
353a
351

LIQUID TREATMENT APPARATUS INCLUDING FLOW CHANNEL, FIRST AND SECOND ELECTRODES, INSULATOR SURROUNDING LATERAL SURFACE OF FIRST ELECTRODE, GAS SUPPLY DEVICE, AND POWER SUPPLY SOURCE

BACKGROUND

1. Technical Field

The present disclosure relates to a liquid treatment apparatus for performing treatments of liquids by utilizing plasma.

2. Description of the Related Art

A technology for purifying or sterilizing liquids by utilizing plasma is known. For example, Japanese Unexamined Patent Application Publication Nos. 2015-33694 and 2015-136644 and International Publication No. 2015/072049 disclose a liquid treatment apparatus that supplies a gas into a liquid and generates plasma in the supplied gas.

SUMMARY

In one general aspect, the techniques disclosed here feature a liquid treatment apparatus including a flow channel, first and second electrodes, an insulator, a gas supply device, and a power supply source. The flow channel is provided for causing a liquid to flow therethrough. At least part of the first electrode is disposed within the flow channel. At least part of the second electrode is disposed within the flow channel. The insulator has a tubular shape and an opening on an end surface of the insulator, and surrounds a lateral surface of the first electrode with a space interposed between the insulator and the lateral surface of the first electrode. The gas supply device supplies a gas to the space and ejects the gas into the liquid via the opening. The power supply source applies a voltage between the first and second electrodes and generates plasma. At least part of the flow channel extends in a first direction which is inclined with respect to a horizontal direction so that the liquid flows obliquely upward with respect to the horizontal direction. The opening is positioned within the at least part of the flow channel.

Additional benefits and advantages of the disclosed embodiments will become apparent from the specification and drawings. The benefits and/or advantages may be individually obtained by the various embodiments and features of the specification and drawings, which need not all be provided in order to obtain one or more of such benefits and/or advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the configuration of a liquid treatment apparatus according to a first embodiment;

FIG. **2** is a sectional view of an example of a first electrode and an example of an insulator according to the first embodiment;

FIG. **3** is a graph illustrating discharging sustainability of the liquid treatment apparatus according to the first embodiment and that according to a comparative example;

FIG. **4** is a sectional view of the configuration of a reaction tank and surrounding components of a liquid treatment apparatus according to the comparative example;

FIG. **5** illustrates the configuration of a liquid treatment apparatus according to a modified example of the first embodiment;

FIG. **6** illustrates the configuration of a liquid treatment apparatus according to a second embodiment;

FIG. **7** is a sectional view of an example of a first electrode and an example of an insulator according to a modified example of the second embodiment; and

FIG. **8** is a sectional view of the configuration of a reaction tank and surrounding components of a liquid treatment apparatus according to the modified example of the second embodiment.

DETAILED DESCRIPTION

Overview of the Disclosure

In a known liquid treatment apparatus, discharging is not stabilized, that is, plasma is not stably generated.

A liquid treatment apparatus according to an aspect of the present disclosure includes a flow channel, first and second electrodes, an insulator, a gas supply device, and a power supply source. The flow channel is provided for causing a liquid to flow therethrough. At least part of the first electrode is disposed within the flow channel. At least part of the second electrode is disposed within the flow channel. The insulator has a tubular shape and an opening on an end surface of the insulator, and surrounds a lateral surface of the first electrode with a space interposed between the insulator and the lateral surface of the first electrode. The gas supply device supplies a gas to the space and ejects the gas into the liquid via the opening. The power supply source applies a voltage between the first and second electrodes and generates plasma. At least part of the flow channel extends in a first direction which is inclined with respect to a horizontal direction so that the liquid flows obliquely upward with respect to the horizontal direction. The opening is positioned within the at least part of the flow channel.

With this configuration, the amount of plasma emission increases and discharging can be stabilized.

The horizontal direction is perpendicular to the direction of gravity, which may be checked by a spirit level, for example.

The liquid treatment apparatus may further include a reaction tank containing the flow channel. The insulator may pass through a wall of the reaction tank and be fixed to the reaction tank.

With this configuration, adjusting of the configuration or the orientation of the reaction tank can easily tilt the flow channel upward with respect to the horizontal direction, and can also easily adjust the tilt angle of the flow channel. By suitably adjusting the tilt angle, discharging stability can be increased.

The reaction tank may be elongated in a direction which intersects the first direction.

With this configuration, merely placing the reaction tank on a horizontal plane can tilt the flow channel upward with respect to the horizontal direction. For example, the reaction tank can stably be supported on the horizontal plane in the state in which the flow channel tilts upward with respect to the horizontal direction.

The reaction tank may be elongated in the first direction and may be disposed such as to be inclined with respect to the horizontal direction.

With this configuration, merely changing the installation orientation of the reaction tank can easily tilt the flow channel upward with respect to the horizontal direction. A general-purpose tubular member, for example, may be used as the reaction tank. Hence, the flexibility in selecting a material for the reaction tank is increased, and a small, lightweight material, for example, can be used, thereby decreasing the size and weight of the liquid treatment apparatus.

A liquid treatment apparatus according to another aspect of the present disclosure includes a flow channel, first and second electrodes, an insulator, a gas supply device, and a power supply source. The flow channel is provided for causing a liquid to flow therethrough. At least part of the first electrode is disposed within the flow channel. At least part of the second electrode is disposed within the flow channel. The insulator has a tubular shape and an opening on an end surface of the insulator, and surrounds a lateral surface of the first electrode with a space interposed between the insulator and the lateral surface of the first electrode. The gas supply device supplies a gas to the space and ejects the gas into the liquid via the opening. The power supply source applies a voltage between the first and second electrodes and generates plasma. The opening is positioned within at least part of the flow channel. The opening is opened obliquely with respect to a flowing direction of the liquid through the at least part of the flow channel.

With this configuration, the amount of plasma emission increases and discharging can be stabilized.

An axis of the insulator may be perpendicular to the end surface and may be inclined with respect to the flowing direction of the liquid.

By inserting a circular tubular insulator, for example, into the flow channel from an oblique direction with respect to the flowing direction of the liquid, the insulator and the flow channel can be combined with each other. It is only required to adjust the orientation of the flow channel and that of the insulator. This allows the use of a general-purpose reaction tank forming a flow channel and a general-purpose insulator. Hence, the flexibility in selecting a material for the reaction tank and that for the insulator is increased, and a small, lightweight material, for example, can be used, thereby decreasing the size and weight of the liquid treatment apparatus.

The axis of the insulator may obliquely intersect the end surface of the insulator.

Obliquely cutting of the end surface of the insulator, for example, can form the face of the opening positioned obliquely with respect to the flowing direction of the liquid. That is, merely changing the shape of the insulator can easily stabilize discharging.

The at least part of the flow channel may extend in a horizontal direction.

Even in a case in which the liquid flows through the flow channel in the horizontal direction, tilting of the face of the opening, which is an outlet for the gas, can stabilize discharging.

Embodiments of the present disclosure will be described below in detail with reference to the accompanying drawings.

All of the embodiments described below illustrate general or specific examples. Numeric values, configurations, materials, components, positions and connection states of the components, steps, and the order of steps illustrated in the following embodiments are only examples, and are not described for limiting the present disclosure. Among the components illustrated in the following embodiments, the components that are not recited in the independent claims which embody the broadest concept of the present disclosure will be described as optional components.

In the drawings, the components are only schematically illustrated and are not necessarily illustrated precisely. The sizes and dimensional ratios of the components in the drawings are not necessarily illustrated as actual sizes and ratios. The substantially same components are designated by like reference numeral, and the same explanation thereof will be simplified or omitted from the second time.

In the specification, terms representing the relationships between components, such as being parallel or perpendicular, terms representing the shapes of components, such as a cylinder, and the ranges of numeric values are not strictly restricted to those described in the specification, and include equivalent terms and ranges. For example, a certain range of numeric values includes allowance of about several percentage of differences.

First Embodiment

[1. Overview]

An overview of a liquid treatment apparatus **1** according to a first embodiment will be described below with reference to FIG. **1**. FIG. **1** illustrates the configuration of the liquid treatment apparatus **1** according to the first embodiment. In FIG. **1**, examples of the sectional configurations of a treatment tank **10** for storing a liquid **2**, a reaction tank **15** for treating the liquid **2** with plasma **5**, and surrounding components are illustrated, and the configurations of other components, such as a piping **20** and a gas supply pump **60**, are schematically illustrated.

As shown in FIG. **1**, the liquid treatment apparatus **1** generates plasma **5** within a gas **3** which is emitted into the liquid **2**. The gas **3** remains within the liquid **2** as bubbles. Concerning the bubbles formed by the gas **3**, a gas-liquid interface **4** may be closed within the liquid **2** or may communicate with an outer space.

The liquid **2** is a subject on which the liquid treatment apparatus **1** performs treatments. The liquid **2** is, for example, water such as tap water or purified water, or an aqueous solution. The liquid **2** circulates between the treatment tank **10** and the reaction tank **15** via the piping **20**. The three white arrows indicated in FIG. **1**, one within the reaction tank **15** and two near the piping **20**, represent the flowing directions of the liquid **2**.

The liquid treatment apparatus **1** generates the plasma **5** within the gas **3** which is emitted into the liquid **2** so as to generate active species, which are reactive specifies, within the liquid **2**. Examples of the active species are hydroxyl radical (OH), hydrogen radical (H), oxygen radical (O), superoxide anion (O^{2-}), monovalent oxygen ion (O^-), and hydrogen peroxide (H_2O_2). The generated active species decompose harmful substances contained in the liquid **2**, for example. The liquid **2** containing active specifies may be used for sterilizing other substances.

[2. Configuration]

The configuration of the liquid treatment apparatus **1** according to the first embodiment will be discussed below.

As shown in FIG. **1**, the liquid treatment apparatus **1** includes a treatment tank **10**, a reaction tank **15**, piping **20**, a first electrode **30**, a first holding portion **35**, a second electrode **40**, a second holding portion **45**, an insulator **50**, a gas supply pump **60**, a liquid supply pump **70**, and a power supply source **80**. The individual elements forming the liquid treatment apparatus **1** will be discussed below in detail.

[2-1. Treatment Tank]

The treatment tank **10** is a container for storing the liquid **2**. The outer configuration of the treatment tank **10** is any shape such as a rectangular parallelepiped, a cylinder, and a sphere. The treatment tank **10** may be a tray having a top portion opened.

The piping **20** is connected to the treatment tank **10**. More specifically, the treatment tank **10** is connected to the reaction tank **15** via the piping **20**. The liquid supply pump **70** is connected to the piping **20**, and the liquid **2** circulates among the treatment tank **10**, the reaction tank **15**, and the piping **20**.

The treatment tank **10** is made of an acid-resistant resin material, for example. The treatment tank **10** is made of fluoropolymers such as polytetrafluoroethylene, silicone rubber, polyvinyl chloride, stainless steel, or ceramic, for example.

[2-2. Reaction Tank and Flow Channel]

The reaction tank **15** is a tank within which at least part of the first electrode **30** and at least part of the second electrode **40** are disposed. More specifically, the first and second electrodes **30** and **40** are disposed to pass through walls of the reaction tank **15**.

The reaction tank **15** contains a flow channel **16** through which the liquid **2** flows. The flow channel **16** is filled with the liquid **2**. At least part of the first electrode **30** and at least part of the second electrode **40** are disposed within the flow channel **16**. The gas **3** (bubbles) supplied from the gas supply pump **60** is emitted to the flow channel **16** via an opening **51** of the insulator **50**. The plasma **5** is generated within the gas **3** as a result of causing the first and second electrodes **30** and **40** to discharge therebetween.

At a position at which the opening **51** of the insulator **50** is formed, the flow channel **16** tilts upward from the upstream side to the downstream side of the flow channel **16** with respect to the horizontal direction. Because of this configuration, in the vicinity of the opening **51** of the insulator **50** which surrounds the first electrode **30**, the liquid **2** flows through the flow channel **16** obliquely upward with respect to the horizontal direction. The face of the opening **51** and the extending direction of the flow channel **16** intersect each other. In this specification, the extending direction of the flow channel **16** is the flowing direction of the liquid **2** through the flow channel **16**. In the example of the liquid treatment apparatus **1** shown in FIG. **1**, the extending direction of the flow channel **16** is a direction in which the flow channel **16** tilts upward at a tilt angle θ with respect to the horizontal direction.

The tilt angle θ of the flow channel **16** is shown in FIG. **1**. The broken line indicated in FIG. **1**, which serves as a base line for the tilt angle θ, is the horizontal direction. The tilt angle θ is 20° to 45°, for example, but it is not restricted to this range. Although in FIG. **1** the tilt angle θ of the flow channel **16** is uniform, it may change from the upstream side to the downstream side.

The sectional surface of the flow channel **16** is a circle, for example. The flow channel **16** is formed so that the area of any sectional surface along the circulating direction of the liquid **2** will be uniform. However, the flow channel **16** is not restricted to this configuration. The sectional surface of the flow channel **16** is not restricted to a circle, and may be a square or another polygon.

In the first embodiment, the reaction tank **15** is elongated in the direction in which it intersects the extending direction of the flow channel **16**. For example, the reaction tank **15** may be a container in the form of a rectangular parallelepiped or a cylinder elongated with respect to the horizontal direction. However, the reaction tank **15** is not limited to this configuration. The reaction tank **15** may be a sealed reservoir tank or a tray having a top portion opened. The reaction tank **15** may be part of the piping **20**.

The reaction tank **15** is made of an acid-resistant resin material, for example. The reaction tank **15** is made of fluoropolymers such as polytetrafluoroethylene, silicone rubber, polyvinyl chloride, stainless steel, or ceramic, for example.

[2-3. Piping]

The piping **20** is provided for forming a circulation path for the liquid **2**, and is constituted by a tubular member such as a pipe, a tube, or a hose. The piping **20** is made of an acid-resistant resin or metal material, for example. The piping **20** is made of fluoropolymers such as polytetrafluoroethylene, silicone rubber, polyvinyl chloride, stainless steel, or ceramic, for example.

In the first embodiment, the piping **20** connects the treatment tank **10** and the liquid supply pump **70** and connects the liquid supply pump **70** and the reaction tank **15** so as to connect the reaction tank **15** and the treatment tank **10**. In this manner, the piping **20** connects the treatment tank **10**, the liquid supply pump **70**, the reaction tank **15**, and the treatment tank **10** in this order so as to form a circulation path for the liquid **2**.

[2-4. First Electrode]

FIG. **2** is a sectional view of an example of the first electrode **30** and an example of the insulator **50** according to the first embodiment. More specifically, FIG. **2** is a cross sectional view of part of the liquid treatment apparatus **1** which passes through the long axis of the first electrode **30**. As shown in FIG. **2**, the first electrode **30** includes an electrode portion **31** and a screw portion **32**.

The first electrode **30** is one of a pair of electrodes for generating the plasma **5**. The first electrode **30** is used as a reaction electrode around which the plasma **5** is generated. The first electrode **30** serves as the anode.

The electrode portion **31** is an elongated cylindrical portion provided on the forward side of the first electrode **30**. The diameter of the electrode portion **31** is as large as to generate the plasma **5**, for example, 2 mm or smaller. In this example, the diameter of the electrode portion **31** is 0.8 mm.

The electrode portion **31** is made of tungsten, for example, but it is not restricted thereto. The electrode portion **31** may be made of another metal such as aluminum, iron, or copper, or an alloy of these metals.

At least part of the first electrode **30** is disposed within the flow channel **16**. More specifically, the electrode portion **31** of the first electrode **30** is disposed within the flow channel **16** of the reaction tank **15**, and contacts the liquid **2**. As shown in FIG. **2**, the electrode portion **31** is surrounded by the insulator **50** with a space **52** therebetween. When the gas **3** is supplied from the gas supply pump **60**, it fills the space **52**, so that the electrode portion **31** is covered by the gas **3** and does not contact the liquid **2**.

In the first embodiment, the electrode portion **31** and the insulator **50** are coaxially disposed. The space **52** is formed between the electrode portion **31** and the insulator **50** so as to surround the entire circumference of the electrode portion **31**. That is, the space **52** is a circular tubular space having a substantially uniform width d**1**. The width d**1** is a distance between the outer lateral surface of the first electrode **30** and the inner lateral surface of the insulator **50**. The width d**1** is 1 to 3 mm, for example.

The screw portion **32** is a metallic member supporting the electrode portion **31**. More specifically, the electrode portion **31** is pressed into the screw portion **32** and is fixed thereto.

The screw portion **32** is electrically connected to the electrode portion **31** and transmits power received from the power supply source **80** to the electrode portion **31**.

The screw portion **32** is a cylindrical portion disposed on the rear side of the first electrode **30**. The diameter of the screw portion **32** is greater than that of the electrode portion **31**, and is 3 mm, for example. The screw portion **32** is made of a metal which is easy to work, such as iron.

The screw portion **32** is supported by the first holding portion **35**. More specifically, a male thread is formed on the outer surface of the screw portion **32** and is screwed with a female thread formed on the first holding portion **35**, so that the screw portion **32** can be supported by the first holding portion **35**.

Through-holes **34** connected to the gas supply pump **60** are provided in the screw portion **32**. The through-holes **34** communicate with the space **52**. Hence, the gas **3** supplied from the gas supply pump **60** passes through the through-holes **34** and the space **52** and is then emitted to the liquid **2** flowing through the flow channel **16** of the reaction tank **15** via the opening **51** of the insulator **50**.

In the first embodiment, two through-holes **34** are provided in the screw portion **32**, as shown in FIG. **2**. This reduces the pressure drop of the gas **3** in the through-holes **34**. However, one through-hole **34** or three or more through-holes **34** may be provided.

As shown in FIG. **2**, an end surface **33** of the first electrode **30** retreats from the face of the opening **51**. An amount of retreat d2 is as large as to such a degree as to reduce the contact between the plasma **5** generated near the end surface **33** and the inner surface of the insulator **50**. More specifically, the amount of retreat d2 of the end surface **33** of the first electrode **30** is 0 to 3 mm.

The amount of retreat d2 is adjustable by axially rotating the screw portion **32**. Rotating of the screw portion **32** axially shifts the electrode portion **31** and the screw portion **32** together with respect to the insulator **50** held by the first holding portion **35**. This makes it possible to vary the position of the end surface **33**.

[2-5. First Holding Portion]

The first holding portion **35** is a member for holding the first electrode **30**. In the first embodiment, the first holding portion **35** holds the first electrode **30** and the insulator **50** and fixes them to certain positions of the reaction tank **15**.

The female thread is formed on the first holding portion **35** and is screwed with the male thread formed on the screw portion **32** of the first electrode **30**. Rotating of the screw portion **32** axially can adjust the axial position of the first electrode **30** with respect to the first holding portion **35**. The insulator **50** is fixed to the first holding portion **35** or the reaction tank **15**. Thus, the position of the end surface **33** of the first electrode **30** with respect to the opening **51** of the insulator **50** can be adjusted. That is, the amount of retreat or the amount of protrusion of the end surface **33** can be adjusted.

[2-6. Second Electrode]

The second electrode **40** is the other one of the pair of electrodes for generating the plasma **5**. The second electrode **40** serves as the cathode. At least part of the second electrode **40** is disposed within the flow channel **16** and contacts the liquid **2**.

In the first embodiment, as shown in FIG. **1**, the second electrode **40** is disposed on the farther upstream side than the first electrode **30** within the flow channel **16**. The second electrode **40** may alternatively be disposed on the farther downstream side than the first electrode **30** within the flow channel **16**. Alternatively, the second electrode **40** may be disposed at a position at which it opposes the first electrode **30** so as to be perpendicular to the flowing direction of the liquid **2**.

The second electrode **40** has an elongated cylindrical portion, for example. In the first embodiment, the configuration, size, and material of the second electrode **40** may be the same as those of the first electrode **30**, or may be different from those of the first electrode **30**.

[2-7. Second Holding Portion]

The second holding portion **45** is a member for holding the second electrode **40**. In the first embodiment, the second holding portion **45** holds the second electrode **40** and fixes it to a certain position of the reaction tank **15**.

[2-8. Insulator]

As shown in FIG. **2**, the insulator **50** is disposed to surround the lateral surface of the first electrode **30** with the space **52** therebetween. The insulator **50** is formed in a tubular shape having the opening **51** at an end surface **53** which contacts the liquid **2**. In the first embodiment, the insulator **50** is an elongated circular tubular member which surrounds the lateral surface of the electrode portion **31** of the first electrode **30**. The insulator **50** passes through the wall of the reaction tank **15** and is fixed to the reaction tank **15** so that the opening **51** can be positioned within the flow channel **16**. More specifically, the insulator **50** is fixed by the first holding portion **35**. The insulator **50** and the first electrode **30** are disposed such that the axial directions thereof coincide with the vertical direction, for example.

The inner diameter of the insulator **50** is greater than the outer diameter of the electrode portion **31**. The electrode portion **31** and the insulator **50** are coaxially disposed. The space **52** is formed in the shape of a circular tube along the entire circumference of the electrode portion **31**, and thus prevents the electrode portion **31** from contacting the insulator **50**. The inner diameter of the insulator **50** is 3 mm, for example, and the outer diameter of the electrode portion **31** is 0.8 mm, for example. The width d**1** of the space **52** is thus calculated to be 1.1 mm.

The gas **3** is supplied to the space **52** and is then emitted into the liquid **2** within the reaction tank **15** via the opening **51**. The emitted gas **3** is diffused into the liquid **2** as bubbles. In this case, the opening **51** has the function of determining the largest size of the bubbles.

The insulator **50** is made of alumina ceramic, for example. Alternatively, the insulator **50** may be made of magnesia, zirconia, quartz, or yttrium oxide.

The shape of the insulator **50** is not restricted to a circular tube, but may be a square tube. The insulator **50** is held by the first holding portion **35**, but may directly be fixed to the wall surface of the reaction tank **15**.

[2-9. Gas Supply Pump]

The gas supply pump **60** supplies the gas **3** into the insulator **50** so as to emit the gas **3** into the liquid **2** via the opening **51**. The gas supply pump **60** is connected to the screw portion **32** of the first electrode **30**, for example. The gas supply pump **60** absorbs surrounding air, for example, and supplies it to the space **52** via the through-holes **34** of the screw portion **32** as the gas **30**. The gas **3** supplied from the gas supply pump **60** is not restricted to air, but may be argon, helium, nitrogen gas, or oxygen gas.

In the first embodiment, the flow rate of the gas **3** supplied from the gas supply pump **60** is 0.5 liters per minute (L/min) or greater. The gas **3** supplied from the gas supply pump **60** pushes the liquid **2** filling the space **52** out of the opening **51** and covers the electrode portion **31**. The gas **3** is emitted into the liquid **2** within the reaction tank **15** via the opening **51**.

[2-10. Liquid Supply Pump]

The liquid supply pump **70** is an example of a liquid supply unit that circulates the liquid **2** between the treatment tank **10** and the reaction tank **15** via the piping **20**. In the first embodiment, the liquid supply pump **70** is disposed at some midpoint in the piping **20**.

[2-11. Power Supply Source]

The power supply source **80** applies a voltage to between the first and second electrodes **30** and **40** so as to generate the plasma **5**. More specifically, the power supply source **80** applies a pulse voltage or an alternating current (AC) voltage to between the first and second electrodes **30** and **40**.

The applied voltage is a positive-polarity high voltage pulse of 2 to 50 kV/cm at a frequency of 1 Hz to 100 kHz, for example. The voltage waveform may be any one of pulse, half-sine, and sine waves. The current flowing between the first and second electrodes **30** and **40** is 1 mA to 3 A, for example. In this example, the power supply source **80** applies a positive pulse voltage having a peak voltage of 4 kV at a frequency of 30 kHz.

[3. Operation]

The operation of the liquid treatment apparatus **1** according to the first embodiment will be described below.

In the liquid treatment apparatus **1**, the gas supply pump **60** supplies the gas **3** while the liquid supply pump **70** is circulating the liquid **2**. The gas **3** is supplied to the space **52** via the through-holes **34** of the screw portion **32**. The liquid **2** which has filled the space **52** is then emitted into the liquid **2** within the reaction tank **15** via the opening **51**. The flow rate of the gas **3** is 0.8 L/min, for example. The gas **3** fills the space **52** and thus covers the electrode portion **31** of the first electrode **30**. Hence, the first electrode **30** is insulated from the liquid **2**.

The power supply source **80** applies a voltage, for example, a positive pulse voltage having a peak voltage of 4 kV at a frequency of 30 kHz, to between the first and second electrodes **30** and **40**. This generates discharging between the end surface **33** of the first electrode **30** and the gas-liquid interface **4**, so that the plasma **5** can be generated within the gas **3** (bubbles) which cover the electrode portion **31**. Active species are generated by the plasma **5** and are absorbed into the liquid **2**. The liquid **2** is circulating, and thus, the active species fill the entirety of the liquid **2**.

[4. Advantages]

Advantages achieved by the liquid treatment apparatus **1** according to the first embodiment will be described below with reference to FIGS. **3** and **4** by means of comparison with a known liquid treatment apparatus.

FIG. **3** is a graph illustrating discharging sustainability of the first embodiment and that of a comparative example. FIG. **4** is a sectional view of the configuration of a reaction tank **115** and surrounding components of a liquid treatment apparatus according to the comparative example.

As shown in FIG. **4**, in the reaction tank **115** of the liquid treatment apparatus according to the comparative example, a flow channel **116** does not tilt with respect to the horizontal direction, and instead, it extends in the horizontal direction. The insulator **50** is disposed perpendicularly to the flowing direction of the liquid **2** through the flow channel **116** (that is, the extending direction of the flow channel **116**). That is, the face of the opening **51** of the insulator **50** is parallel with the extending direction of the flow channel **116** (more specifically, the horizontal direction).

The present inventor performed treatments of a subject liquid by using the liquid treatment apparatus of the comparative example shown in FIG. **4**. The subject liquid was composite water containing 150 ppm of silica (Na_2SiO_3), 25.1 ppm of $CaCl_2.2H_2O$, 42.0 ppm of $MgSO_4.7H_2O$, 99 ppm of $NaHCO_3$, and 21.5 ppm of $KHCO_3$. The diameter of the insulator **50** was 10 mm.

As indicated by plotting of the cross mark "X" in FIG. **3**, in the liquid treatment apparatus of the comparative example, discharging became unstable and stopped in 50 hours after discharging started. More specifically, discharging power was substantially constant with the lapse of time, and immediately before discharging stopped, discharging became unstable with a decreased amount of light emission.

In contrast, a liquid treatment apparatus according to an aspect of the present disclosure includes a flow channel **16**, first and second electrodes **30** and **40**, an insulator **50**, a gas supply pump **60**, and a power supply source **80**. The flow channel **16** is provided for causing a liquid **2** to flow therethrough. At least part of the first electrode **30** and at least part of the second electrode **40** are disposed within the flow channel **16**. The insulator **50** is formed in a tubular shape and includes an opening **51** at an end surface **53**. The insulator **50** surrounds the lateral surface of the first electrode **30** with a space **52** therebetween. The gas supply pump **60**, which serves as a gas supply device, supplies a gas **3** to the space **52** and emits the gas **3** into the liquid **2** via the opening **51**. The power supply source **80** applies a voltage to between the first and second electrodes **30** and **40** and generates plasma **5**. At least part of the flow channel **16** extends in a direction which is inclined with respect to the horizontal direction so that the liquid **2** can flow obliquely upward with respect to the horizontal direction. The opening **51** is positioned within this part of the flow channel **16**.

With this configuration, the amount of plasma emission increases and discharging becomes stable. More specifically, as indicated by plotting of the circles in FIG. **3**, discharging stably continues up to more than 100 hours. The reason for this may be as follows. The distance between the gas-liquid interface **4** and the end surface **33** of the first electrode **30** is decreased, so that the shape of the bubbles of the gas **3** becomes smaller and is also stabilized.

As described above, the liquid treatment apparatus **1** according to the first embodiment can stabilize discharging.

Modified Example

A modified example of the first embodiment will be described below with reference to FIG. **5**. FIG. **5** illustrates the configuration of a liquid treatment apparatus **101** according to the modified example.

As shown in FIG. **5**, the liquid treatment apparatus **101** according to this modified example is different from the liquid treatment apparatus **1** of the first embodiment in that it includes a reaction tank **115** instead of the reaction tank **15** and also includes a support portion **190** for supporting the reaction tank **115**. The liquid treatment apparatus **101** will be described below mainly by referring to the points different from the counterpart of the first embodiment, and a detailed explanation of the same points will be simplified or omitted.

The reaction tank **115** is the same as that of the above-described comparative example shown in FIG. **4**. The reaction tank **115** is configured in a shape elongated in the extending direction of the flow channel **116**. The reaction tank **115** is formed in a circular tube or a square tube, for example. In the vicinity of the opening **51** of the insulator **50** which surrounds the first electrode **30**, the liquid **2** flows through the flow channel **16** obliquely upward with respect to the horizontal direction. In this modified example, the face of the opening **51** and the extending direction of the flow channel **116** (that is, the flowing direction of the liquid **2**) are parallel with each other.

As shown in FIG. **5**, the reaction tank **115** is disposed to tilt with respect to the horizontal direction. In this modified example, the reaction tank **115** is supported by the support portion **190** so as to tilt at a tilt angle θ with respect to a horizontal plane **191**. The reaction tank **115** is disposed obliquely, so that the flow channel **116** also tilts upward from the upstream side to the downstream side of the flow channel **116** with respect to the horizontal direction.

In this modified example, the insulator **50** and the first electrode **30** are disposed to vertically pass through the side wall of the reaction tank **115**. The insulator **50** and the first electrode **30** thus tilt with respect to the vertical direction and the horizontal direction. The axial direction of the insulator **50** and that of the first electrode **30** are perpendicular to the flowing direction of the liquid **2** through the flow channel **116**.

The support portion **190** is a member that is positioned between the reaction tank **115** and the horizontal plane **191** and supports the reaction tank **115** in a tilting state. The shape, size, and material of the support portion **190** are not restricted to a particular shape, size, and material. The member that supports the reaction tank **115** in a tilting state is not limited to the support portion **190**. For example, the reaction tank **115** may be fixed to a predetermined wall surface such that the flow channel **116** is positioned obliquely upward. The reaction tank **115** may alternatively be suspended from above.

As described above, in the liquid treatment apparatus **101** according to this modified example, by disposing the reaction tank **115** obliquely with respect to the horizontal direction, the flow channel **116** also tilts upward from the upstream side to the downstream side with respect to the horizontal direction.

With this configuration, discharging can be stabilized, as in the first embodiment.

Second Embodiment

A second embodiment will be described below.

In the first embodiment, the flow channel **16** tilts upward from the upstream side to the downstream side with respect to the horizontal direction. In the second embodiment, a flow channel **116** extends in the horizontal direction. The second embodiment will be described below mainly by referring to the points different from the first embodiment, and a detailed explanation of the same points will be simplified or omitted.

FIG. **6** illustrates the configuration of a liquid treatment apparatus **201** according to the second embodiment. As shown in FIG. **6**, the liquid treatment apparatus **201** is different from the liquid treatment apparatus **1** of the first embodiment in that it includes a reaction tank **115** instead of the reaction tank **15** and that the first electrode **30** and the insulator **50** are disposed to tilt with respect to the flow channel **116**.

The reaction tank **115** is the same as the reaction tank **115** used in the modified example of the first embodiment shown in FIG. **5**. In the second embodiment, the support portion **190** is not provided, and the reaction tank **115** is disposed along the horizontal direction. More specifically, the flow channel **116** contained in the reaction tank **115** extends in the horizontal direction, and the liquid **2** flows in the horizontal direction.

In the second embodiment, the face of the opening **51** of the insulator **50** tilts upward from the upstream side to the downstream side of the flow channel **116**. That is, the opening **51** is opened obliquely with respect to the flowing direction of the liquid **2** through the flow channel **116**. The tilt angle of the face of the opening **51** is 20° to 45°, for example, but it is not restricted to this range.

The axial direction of the insulator **50** is perpendicular to the face of the opening **51**, and tilts with respect to the extending direction of the flow channel **116**. More specifically, the insulator **50** is a circular tubular member or a square tubular member including an end surface **53** which is perpendicular to the axial direction of the insulator **50**. The insulator **50** is disposed to obliquely intersect the extending direction of the flow channel **116**.

As described above, in the liquid treatment apparatus **201** according to the second embodiment, the face of the opening **51** of the insulator **50** tilts upward from the upstream side to the downstream side of the flow channel **116**.

With this configuration, the distance between the gas-liquid interface **4** and the end surface **33** of the first electrode **30** is decreased, so that the shape of the bubbles of the gas **3** becomes smaller and is also likely to be stabilized. As a result, the liquid treatment apparatus **201** of the second embodiment, as well as the counterpart of the first embodiment, can stabilize discharging.

Modified Example

A modified example of the second embodiment will be described below with reference to FIGS. **7** and **8**. FIG. **7** is a sectional view of an example of a first electrode **30** and an example of an insulator **350** according to the modified example. FIG. **8** is a sectional view of the configuration of a reaction tank **115** and surrounding components of a liquid treatment apparatus according to the modified example.

As shown in FIGS. **7** and **8**, the liquid treatment apparatus of this modified example is different from the liquid treatment apparatus **201** of the second embodiment in that it includes the insulator **350** instead of the insulator **50**. The modified example will be described below mainly by referring to the points different from the second embodiment, and a detailed explanation of the same points will be simplified or omitted.

As shown in FIG. **7**, in this modified example, an end surface **353** of the insulator **350** is flush with the face of an opening **351** and also tilts with respect to the axial direction of the insulator **350**. More specifically, the insulator **350** is configured in a shape in which part of a circular tube is obliquely cut. The cut plane corresponds to the end surface **353** and the face of the opening **351**. The end surface **353** includes an end surface portion **353*a*** on the shorter side of the insulator **350** and an end surface portion **353*b*** on the longer side of the insulator **350**.

The end surface **33** of the first electrode **30** retreats farther backward than the face of the opening **351**. The face of the opening **351** is indicated by the long dashed dotted line which connects the end surface portions **353*a*** and **353*b*** in FIG. **7**. More specifically, as shown in FIG. **7**, the end surface **33** retreats farther backward than the end surface portion **353*a***. The end surface **33** may alternatively protrude farther than the end surface portion **353*a*** if it retreats farther backward than the face of the opening **351**.

As shown in FIG. **8**, the insulator **350** and the first electrode **30** are disposed such that the axial directions thereof are positioned perpendicularly to the extending direction of the flow channel **116**. In this case, the end surface portion **353*b*** is positioned on the upstream side of the flow channel **116**, while the end surface portion **353*a*** is positioned on the downstream side of the flow channel **116**.

With this configuration, the face of the opening **351** tilts upward from the upstream side to the downstream side of the flow channel **116**.

As described above, in the liquid treatment apparatus of this modified example, the face of the opening **351** of the insulator **350** tilts upward from the upstream side to the downstream side of the flow channel **116**.

With this configuration, discharging can be stabilized, as in the second embodiment.

Other Embodiments

The liquid treatment apparatuses according to one or plural aspects have been described through illustration of the embodiments. However, the present disclosure is not restricted to the above-described embodiments. Without departing from the spirit and scope of the disclosure, various modifications apparent to practitioners skilled in the art may be made to the embodiments and components in the different embodiments may be combined with each other to form other aspects of the disclosure. Such aspects are also encompassed within the scope of the disclosure.

In the above-described embodiments, the position of the end surface **33** of the electrode portion **31** is adjustable by rotating the screw portion **32**. However, the positional relationship between the electrode portion **31** and the insulator **50** may be fixed. More specifically, a female thread may not be formed on the first holding portion **35**, and a male thread may not be formed on the screw portion **32**.

In the above-described embodiments, the first electrode **30** includes the electrode portion **31** and the screw portion **32**. However, the first electrode **30** may be a single bar-like electrode. The first electrode **30** may be a square tubular or flattened electrode. The second electrode **40** may also be formed in a similar manner. Additionally, plural first electrodes **30** and/or plural insulators **50** may be provided.

In the liquid treatment apparatus **1**, **101**, or **201**, at least one of the first and second holding portions **35** and **45** may be omitted, and at least the corresponding one of the first and second electrodes **30** and **40** may directly be fixed to the reaction tank **15** or **115**.

In the second embodiment, the flow channel **116** may not be parallel with the horizontal direction, but may tilt with respect to the horizontal direction.

In the modified example of the second embodiment, the insulator **350** is configured in a shape in which the end surface **353** is obliquely cut. However, the insulator **350** is not restricted to this configuration. The end surface **353** may be a curved surface.

Various changes, replacements, addition, omission may be made to the above-described embodiments within the spirit and scope of the disclosure defined by the following claims and their equivalents.

What is claimed is:

1. A liquid treatment apparatus comprising:

a flow channel for causing a liquid to flow therethrough;

a first electrode at least part of which is disposed within the flow channel;

a second electrode at least part of which is disposed within the flow channel;

an insulator having a tubular shape and an opening on an end surface of the insulator, the insulator surrounding a lateral surface of the first electrode with a space interposed between the insulator and the lateral surface of the first electrode;

a gas supply device that supplies a gas to the space and ejects the gas into the liquid via the opening; and

a power supply source that applies a voltage between the first and second electrodes and generates plasma, wherein

at least part of the flow channel extends in a first direction which is inclined with respect to a horizontal direction so that the liquid flows obliquely upward with respect to the horizontal direction, and

the opening is positioned within the at least part of the flow channel.

2. The liquid treatment apparatus according to claim **1**, further comprising:

a reaction tank containing the flow channel,

wherein the insulator passes through a wall of the reaction tank and is fixed to the reaction tank.

3. The liquid treatment apparatus according to claim **2**, wherein the reaction tank is elongated in a direction which intersects the first direction.

4. The liquid treatment apparatus according to claim **2**, wherein the reaction tank is elongated in the first direction and is disposed such as to be inclined with respect to the horizontal direction.

5. A liquid treatment apparatus comprising:

a flow channel for causing a liquid to flow therethrough;

a first electrode at least part of which is disposed within the flow channel;

a second electrode at least part of which is disposed within the flow channel;

an insulator having a tubular shape and an opening on an end surface of the insulator, the insulator surrounding a lateral surface of the first electrode with a space interposed between the insulator and the lateral surface of the first electrode;

a gas supply device that supplies a gas to the space and ejects the gas into the liquid via the opening; and

a power supply source that applies a voltage between the first and second electrodes and generates plasma, wherein

the opening is positioned within at least part of the flow channel,

the opening is opened obliquely with respect to a flowing direction of the liquid through the at least part of the flow channel, and

wherein an axis of the insulator obliquely intersects the end surface.

6. The liquid treatment apparatus according to claim **5**, wherein the at least part of the flow channel extends in a horizontal direction.

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